UNCLASSIFIED

AD NUMBER

AD872828

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution: Further dissemination only as directed by US Army Test and Evaluation Command [USATECOM], Aberdeen Proving Ground, Maryland 21005; 30 Apr 1970 or higher DoD authority.

AUTHORITY

USATEC, ltr, 14 Dec 1970.

THIS PAGE IS UNCLASSIFIED

30 April 1970

Materiel Test Procedure 4-1-005*
Aberdeen Proving Ground

U. S. ARMY TEST AND EVALUATION COMMAND
BACKGROUND DOCUMENT

THE DOPPLER VELOCIMETER

AD 872828

1. INTRODUCTION

The Doppler velocimeter performs a single function; i.e., the measurement of radial velocity. This measurement, coupled with other information, can yield highly accurate data otherwise difficult to acquire. This pamphlet reviews how the Doppler velocimeter supplemented by other instrumentation is used to obtain required ballistic data. The modified Hawk CW Illuminator (Figure 1) is an example of a Doppler velocimeter.

2. SCOPE

The Doppler principle for radial velocity measurements is explained, and a generalized field instrumentation array for Doppler velocimeter operations is supplied as a guide for test directors in planning for specific field test objectives. Projection of the measured radial velocity upon the direction of projectile motion to obtain actual projectile velocity is explained. Only passive Doppler technology is considered; i.e., the test item carries no beacon or transponder, but merely reflects the radio-frequency waves emanating from the Doppler velocimeter transmitter.

3. THE DOPPLER PRINCIPLE

Radio-frequency waves will reflect from flat metallic surfaces in a manner comparable with the reflection of visible light from mirrors. Radar uses this principle to detect and measure distances to aircraft, ships, missiles, etc. The radar transmits a pulse; this is reflected from the target and then received by the radar. The time required for the pulse to make the round trip is measured. The slant range may then be computed, based on the known velocity of propagation.

The Doppler velocimeter operates on a different principle. A continuous radio-frequency wave is transmitted. This is reflected back from the target to the velocimeter. The velocimeter output is an alternating current signal whose frequency is the difference between the frequencies of the transmitted and the received (reflected) waves. If the target is stationary in respect to the velocimeter, the transmitted and received frequencies are identical and the difference in frequency is zero. If, however, there is relative motion between the velocimeter and target, the reflected signal will undergo a frequency shift as observed at the velocimeter. This difference in frequency - termed the "Doppler shift" - is directly proportional to the rate at which the distance from the velocimeter to the target is changing; i.e., it is directly proportional to the "radial velocity."

3.1 RADIAL VELOCITY AS RELATED TO TARGET VELOCITY

*Supersedes Interim Pamphlet 80-17.

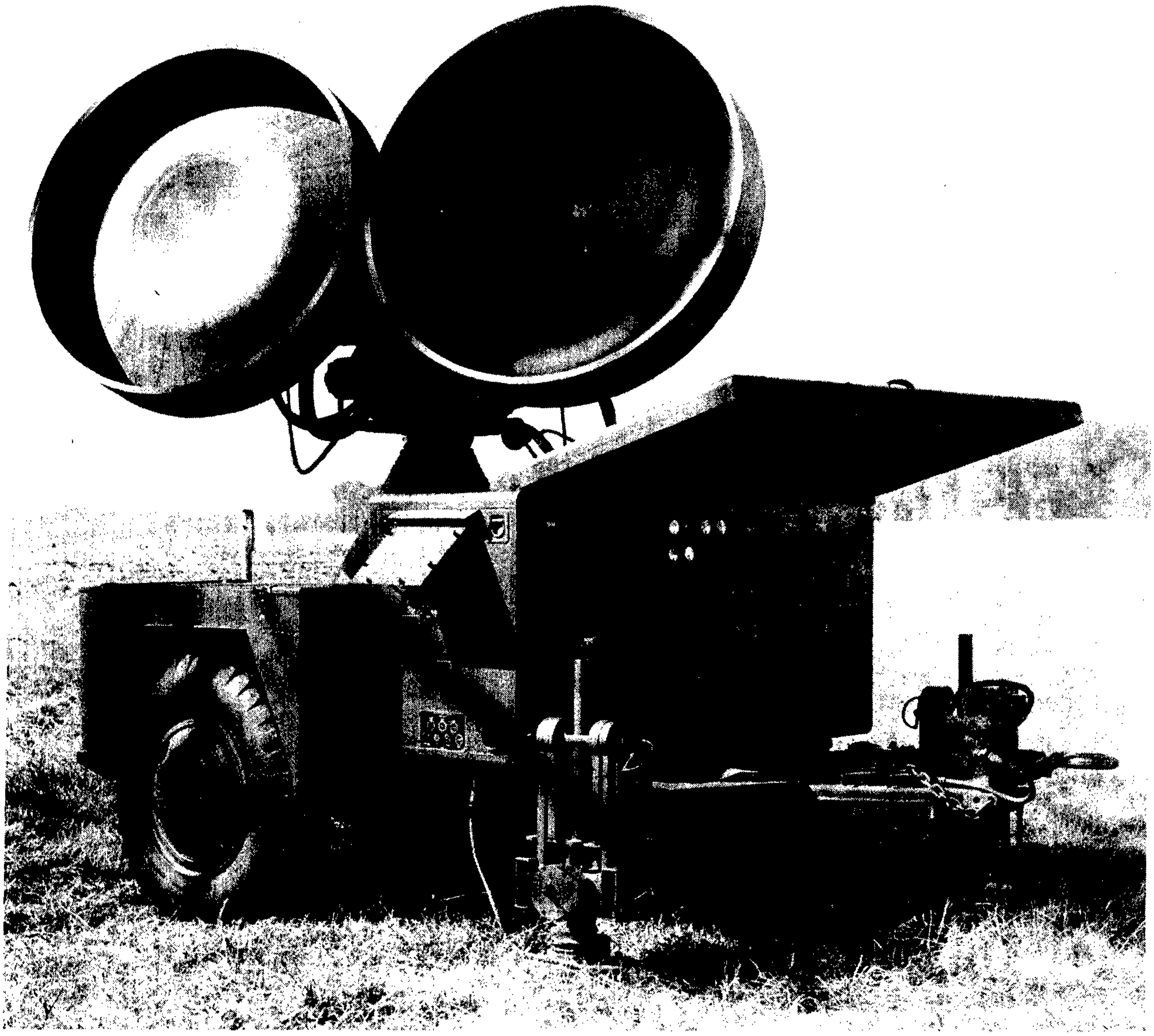

Figure 1. Doppler Velocimeter (Modified Hawk CW Illuminator).

Usually the "radial velocity" is only one component of the target's absolute velocity. As an extreme example, consider a target moving in a circle centered at the velocimeter: obviously, the motion of this target relative to the velocimeter is zero, so that the latter will record zero as the radial velocity of the target. The relationship between radial velocity and target velocity is illustrated by Figure 2. Consider a target at point X at a distance, r, from the velocimeter at time, t. The target can then be considered to be on the surface of a sphere of radius, r, centered at the velocimeter location. Some time, Δt, later the target is at point Y on the surface of a concentric sphere whose radius is $r + \Delta r$.

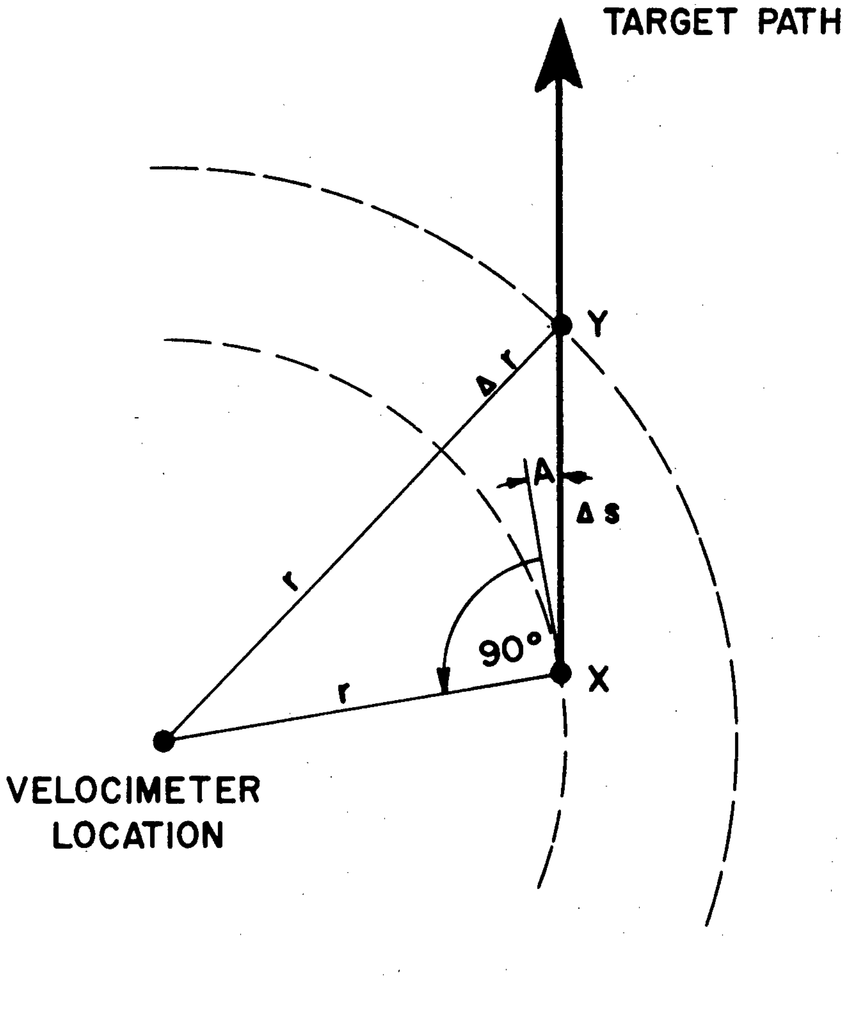

Figure 2. Relationship Between Radial Velocity and Target Velocity.

The average radial velocity over the finite time interval illustrated by Figure 2 would thus be $\Delta r/\Delta t$, and the corresponding average target velocity would be $\Delta s/\Delta t$. Practically, the $\Delta r/\Delta t$ ratio for a given time, t, may be regarded as the true (as opposed to average) radial velocity, V_r, for that time instant, since it is based on the velocimeter's continuous record of frequency difference as a function of time. The corresponding target velocity, V_T, is given by

$$(1) \quad V_T = V_r/\sin A ,$$

where the angle of projection, A, must be measured by supplementary instrumentation (usually photographic). Thus, for a given instant in time, target velocity can be determined from radial velocity if the direction of motion of the target relative to the velocimeter is known.

3.2 RADIAL VELOCITY AND RADIAL DISTANCE

The radial velocity derived from the velocimeter can, under proper circumstances, be useful in determining distance. In a continuing tracking operation the velocimeter data results in a continuing record of the target radial velocity as a function of time. By integrating this record between time limits, t_1 and t_2, the corresponding change in radial distance is found, i.e.,

$$(2) \quad R_2 - R_1 = \int_{t_1}^{t_2} V_r \, dt$$

where R_2 is the radial distance from the velocimeter to the target at time t_2, and R_1 is the radial distance from the velocimeter to the target at time t_1. Were a "fix" on the target at time t_1 provided, i.e., R_1 known, the continuous records of radial velocity could be integrated to provide a continuous record of the radial distance from the velocimeter to the target. The velocimeter thus provides a means of continuous ranging to a target once an initial starting point is established.

4. OPERATIONAL CONSTRAINTS

Several contraints apply in utilizing the Doppler velocimeter. The velocimeter location should be relatively free of firing shock and blast. The preferable location is to the rear and slightly to the side of the weapon. The velocimeter must acquire and then track the target, and to minimize this problem it is well to place the velocimeter in, or very close to, the vertical plane in which the target will be launched. An early segment of the trajectory should be included within the initial (pre-track) field of view of the velocimeter to permit early target acquisition. On the other hand, the corresponding tracking rate required of the velocimeter must not exceed its maximum capability. Also, the longer the target remains in the initial field of view, the less difficult is acquisition. Some compromise between the applicable restraints is thus necessary. High-elevation firings especially create problems relative to velocimeter placement.

The velocimeter is sensitive to radial motion of any item within its field of view. Any object that moves can create a false signal. At low firing elevations guy wires, or other metallic objects free to move or vibrate, are potential sources of difficulty. The velocimeter cannot differentiate between a projectile, missile, or discarded parts. The likelihood of getting good records in the presence of discarded parts is severely reduced as the size or number of parts increases. In some cases the velocimeter will lock on and track discarded parts preferentially since they may provide a better reflector than the target itself.

The base of a projectile makes a reasonably good reflector. If the projectile is fired at a low angle of elevation, the base remains well oriented as a radar reflector during the entire flight. At a high angle of fire, however, velocimeter tracking beyond the trajectory summit is difficult because beyond this point the projectile base orientation becomes increasingly unfavorable and the side of the projectile presents a poor reflecting surface.

Exhaust gases of boosted projectiles or rocket motors create problems. Their highly ionized gases both reflect and attenuate radio-frequency waves. The severity of this problem varies from propellant to propellant and must be explored prior to undertaking extensive testing.

The Hawk velocimeter (Figure 1) is incapable of tracking or recording radial velocities below 250 or above 10,000 feet per second or of tracking faster than 24° per second; maximum range is 40,000 feet, accuracy is ± 0.1 percent standard deviation for a single measurement of radial velocity. The beam width is some 2 degrees.

5. PERIPHERAL EQUIPMENT AND DATA REQUIREMENTS

The output of the velocimeter is an alternating current whose frequency is directly proportional to the radial velocity. This is recorded on magnetic tape with other pertinent analog information such as a time base and the synchronization signals required for data reduction purposes.

The equation in paragraph 3.2 dictates that a fix in time and space is required in the data reduction process. This "fix" can be obtained by utilizing photogrammetric methods or velocity measuring equipment such as sky screens, described in MTP 4-2-805.

6. APPLICATIONS

Paragraphs 3.1 and 3.2 establish the basic methodology for using the Doppler velocimeter. Target velocity and position as functions of time can be obtained provided that auxiliary data are available. The auxiliary data may be obtained from other instrumentation, from purely geometrical or ballistic considerations, or from a combination of these.

6.1 DIRECT FIRE RESISTANCE FIRINGS

Resistance firings are conducted to determine the ballistic coefficient

of projectiles. These tests are usually conducted as part of the ammunition accuracy phase against vertical targets. The typical range layout shown in Figure 3 includes two sky screens supplementary to the velocimeter. The sky screens measure muzzle velocity, and, more important, they identify specific space-time positions that are required for reduction of the velocimeter trajectory data. The velocimeter is placed slightly off the line of fire and behind the weapon. Ideally, the velocimeter should be placed so as to require minimal tracking to cover the trajectory from a point just forward of the muzzle to the target. The sky screens should be far enough forward of the muzzle - usually 200 to 300 feet - to be "tripped" shortly after the velocimeter has acquired the round.

6.2 POSITION VERSUS TIME

The determination of position versus time is of special importance when the round is not following a ballistic trajectory. This is generally true of boosted projectiles and rockets prior to burnout. A corresponding range layout is shown schematically in Figure 4. The launch angle of elevation and the projectile (or rocket) size and velocity determine the actual range geometry and instrumentation layout. The immediate post-launch trajectory is determined by photogrammetric means. Cameras are placed to provide coverage from muzzle or launcher (or nearly so) to the region forward of the muzzle or launcher where velocimeter coverage will occur. Boresight cameras or cinetheodolites (photo-theodolites) to the rear of the launcher provides coverage after the round leaves the immediate post-launch area. Boresight coverage must continue for as long as data are required. The early portion of the trajectory is triangulated by the side cameras, while the remainder of the trajectory is recreated by integrating the expression of equation (1) paragraph 3.1, with respect to time, sin A as a function of time being provided by either the boresight cameras or the cinetheodolites. A common timing system for all instrumentation is essential.

6.3 OTHER APPLICATIONS

Paragraph 6.2 provides the basis for completely exploiting the velocimeter capabilties. In many test plans, the maximum degree of coverage as described will not be warranted. This is frequently true of items in an early stage of development for which only limited data may be required by the development agency. In these cases, part of the instrumentation may be dispensed with in favor of ballistic or other assumptions sufficiently valid for results within the specified accuracy limits. Generally, however, reduction of the raw velocimeter data requires at least one other piece of instrumental information. The test director is advised to consult instrumentation and data reduction specialists prior to undertaking tests utilizing the velocimeter.

REFERENCES

1. MTP 4-2-805, Projectile Velocity Measurements.

2. Gill, T. P., The Doppler Effect, Lagos Press Limited, 1965.

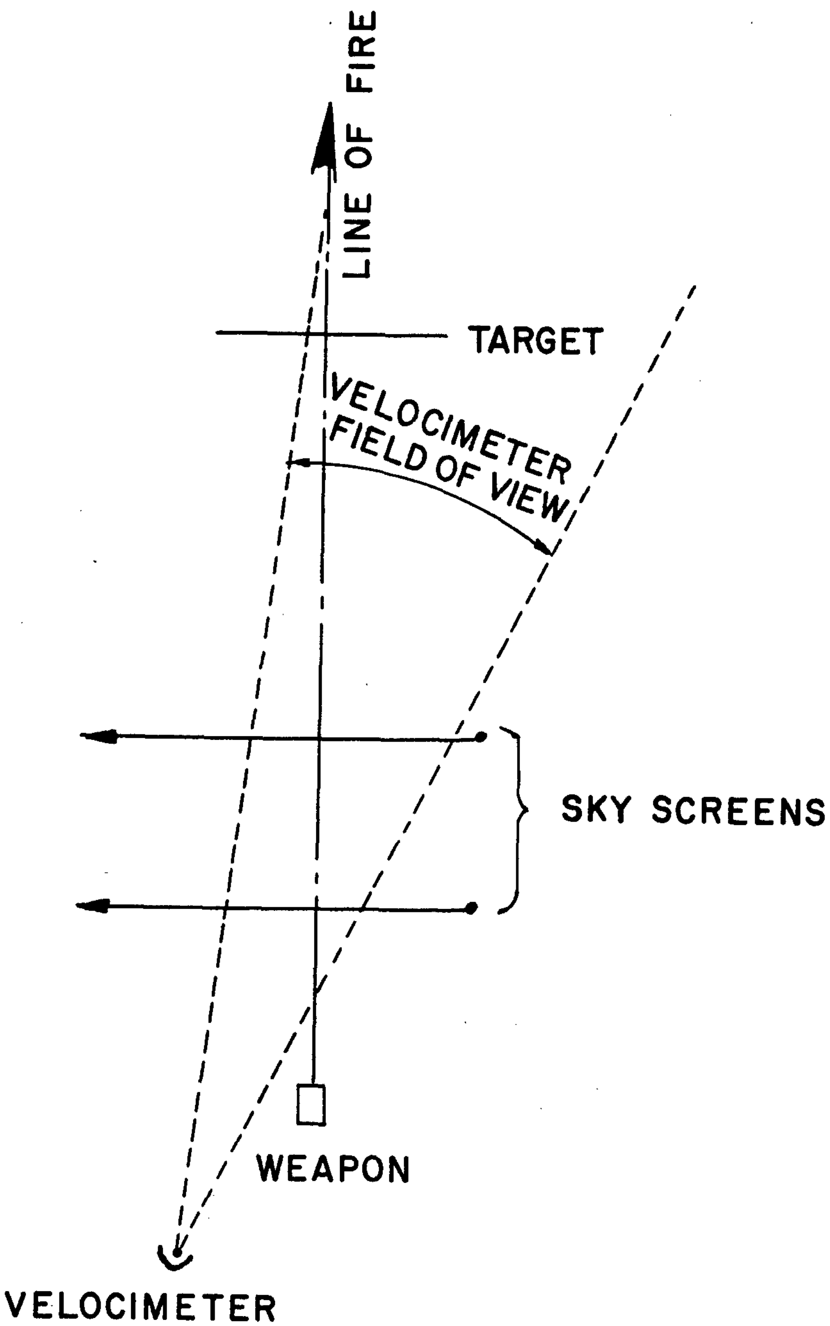

Figure 3. Velocimeter Setup for Resistance Firing.

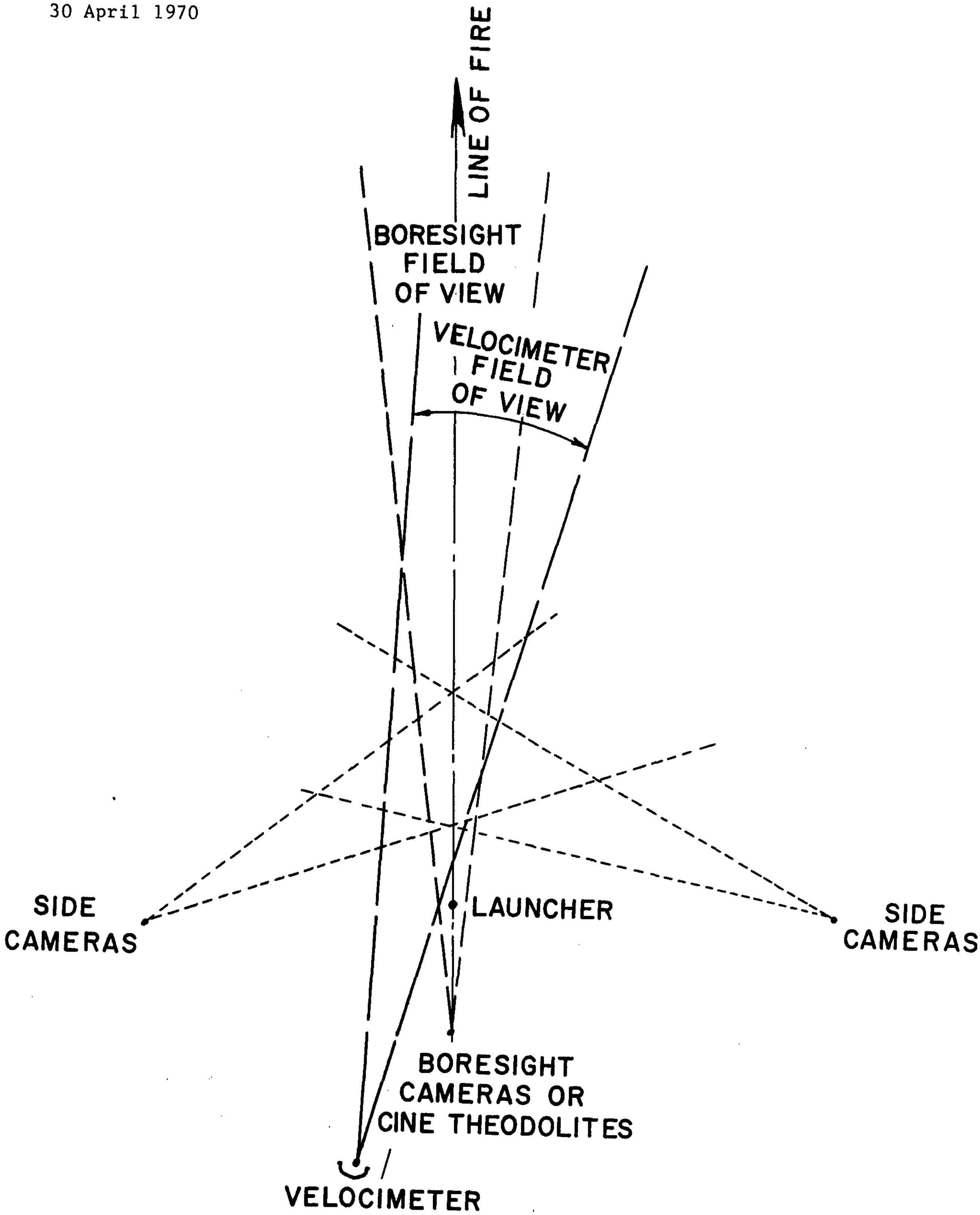

Figure 4. Firings for Position Versus Time.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) US Army Test and Evaluation Command (USATECOM) Aberdeen Proving Ground, Maryland 21005	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP ------------

3. REPORT TITLE
US Army Test and Evaluation Command Materiel Test Procedure 4-1-005, Background Document, "The Doppler Velocimeter."

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final

5. AUTHOR(S) (First name, middle initial, last name)
----

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 April 1970	10	2

8a. CONTRACT OR GRANT NO. DA-18-001-AMC-1045(R) b. PROJECT NO. AMCR 310-6 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) MTP 4-1-005 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ----------------

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals,-WITH THE EXCEPTION OF AUSTRALIA, CANADA, AND UNITED KINGDOM,-may be made only with prior approval of HQ,USATECOM.

11. SUPPLEMENTARY NOTES -------------	12. SPONSORING MILITARY ACTIVITY Headquarters US Army Test and Evaluation Command Aberdeen Proving Ground, Maryland 21005

13. ABSTRACT
This Background Document provides general information on the utilization of the Doppler Velocimeter, supplemented by other instrumentation, for obtaining ballistic data. The Doppler principle for radial velocity measurements is explained and a generalized field instrumentation array for Doppler Velocimeter operations is supplied as a guide in planning for specific field testing objectives.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6811

UNCLASSIFIED
Security Classification

A-31408

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ballistic Data Measurements						
Doppler Velocimeter						
Passive (R.F.) Doppler Principles						

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

UNCLASSIFIED
Security Classification

A-31409